Adaptive Approach for Damping Power System Oscillations using STATCOM

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Abstract

Static synchronous compensator (STATCOM) is a shunt connected FACTS controller which can improve the stability of the system. It provides sufficient damping during disturbance in the power system. This paper deals with an adaptive approach for power oscillation damping controller using STATCOM. It uses space vector pulse width modulation (SVPWM) for generating gate pulses required for the operation of the STATCOM. Output voltage of STATCOM depends on the gate pulses given to it. Among different pulse width modulation techniques, SVPWM technique is implemented as it is easy to achieve digital realization and dc bus utilization. SVPWM is controlled by proportional-integral (PI) controller whose output is given to it. A phase locked loop (PLL) is used to synchronize the grid voltage with ac output current of STATCOM. This method is effective in damping oscillations in the power system. A simulink model for this is created using MATLAB version R2015a. The simulation and experimental results are used to verify the effectivity of the proposed method to provide power oscillation damping.

Keywords - *Static synchronous compensator (STATCOM), space vector pulse width modulation (SVPWM), flexible ac transmission devices (FACTS), proportional-integral (PI) controller.*

I. INTRODUCTION

Electrical power is being used by all for operating various machines and loads. It is used for domestic purposes, industrial purposes, etc. In India, new industries are emerging day by day. Urbanization is taking place on wide range. Whenever there is locality or industry, there is need of electrical power for sure. There is one way of providing electrical supply to the consumers and industries is that to build new electrical power transmission lines which will carry power to the required areas. However, building new transmission lines is not economical. Cost of transmission lines is not affordable. In addition, there are many constraints such as the fuel availability, political acceptability, environment concerns in starting a new generation unit[3]. Hence, the utilities are forced to rely on already existing infra-structure instead of building new transmission lines. In order to maximize the efficiency of generation, transmission and distribution of electric power, the transmission networks are very often pushed to their physical limits, where outage of lines or other equipment could result in the rapid failure of the entire system. The power system may be thought of as a nonlinear system with many lightly damped electromechanical modes of oscillation[11].

Power system oscillations are a characteristic of the system and they are inevitable. However, from an operating point of view, oscillations are acceptable as long as they decay[13]. Power system oscillations are initiated by normal small changes in system loads, and they become much worse following a large disturbance. The traditional approach employs power system stabilizers (PSS) in order to damp those oscillations. PSSs are effective but they are usually designed for damping local modes. In large power systems, they may not provide enough damping for inter-area modes. So, more efficient substitutes are needed other than PSS[11]. This makes one think of an alternate solution for reducing the scarcity of power by improving the quality of the existing power. To improve the reliability and deliver the energy at the lowest possible cost with improved power quality, power supply industries require increased flexibility in the power system. The power industry can handle these challenges with the power electronics based technology of Flexible AC Transmission Systems (FACTS)[3].

The VSC based FACTS controllers have several advantages over the variable impedance type. The VSC based STATCOM response is much faster than the variable impedance type SVC. The STATCOM requires less space than the SVC for the same rating. It can supply the required reactive power even at low values of the bus voltage. In addition, a STATCOM can supply active power if it has an energy source or large energy storage at its dc terminals. It can also be designed to have inbuilt, short-term overload capability[3].

II. PROPOSED SYSTEM

We have a three phase system in which a generator acting as a three phase source is connected to the three phase inductive load. Under normal condition, three phase source is supplying the required voltage and current to the load. If at any instant, the fault occurs on any of the phases, then the parameters of the machines such as voltage, current, impedance may change from their nominal ranges.

The fault in power system causes overcurrent, undervoltage, unbalance of phases. This results in the interruption of the normal operation of the network, failure of equipments, electrical fires, etc. This abnormal condition causes damage to the equipment or says to the load. To protect the load from damage, a flexible ac transmission device STATCOM i.e. static synchronous compensator is connected between the supply and load. The block diagram of proposed system is shown in figure 1.

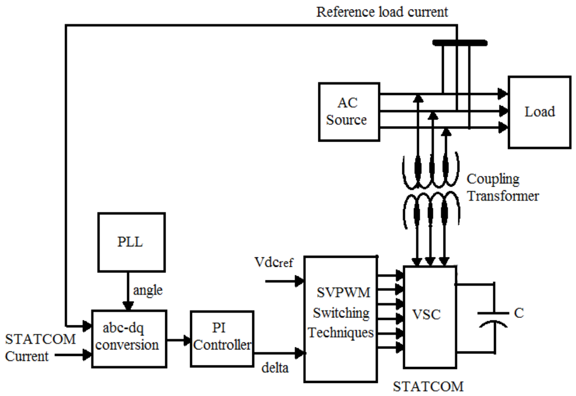


Figure 1: Block diagram of proposed system

Phase locked loop is used to detect the phase angle of the grid voltage in order to synchronize the delivered power i.e. it is used to synchronize the inverter output current with the grid voltage. STATCOM consists of voltage source converter (VSC), dc link capacitor as input to the STATCOM, coupling transformer for connecting the converter to high voltage power system. The dc voltage is converted to ac voltage with the appropriate valve turn on, turn off sequence. By controlling the STATCOM, ac voltage at the output of STATCOM can be controlled which is then supplied to the load. For this reason, STATCOM needs a controller. In this project, a proportional integral (PI) controller is used. A proportional-integral control scheme is implemented to achieve stable current at the point where load is connected. Input to the controller is difference of load current and compensator output current. The error produced is then processed by a PI controller, the output of which is an angle delta, which in turn is provided to the pulse width modulation (PWM) signal generator. In other words, PI controller processes the error signal and generates the required angle to drive the error to zero.

III. STATIC SYNCHRONOUS COMPENSATOR (STATCOM)

STATCOM is a shunt connected FACTS device. It is made up of a coupling transformer, a VSC and a dc energy storage device. STATCOM is capable of exchanging reactive power with the transmission line because of its small energy storage device, i.e., small dc capacitor, if this dc capacitor is replaced with dc storage battery or other dc voltage source, the controller can exchange real and reactive power with the transmission system, extending its region of operation from two to four quadrants. A functional model of a STATCOM is shown in figure 2[2][12].

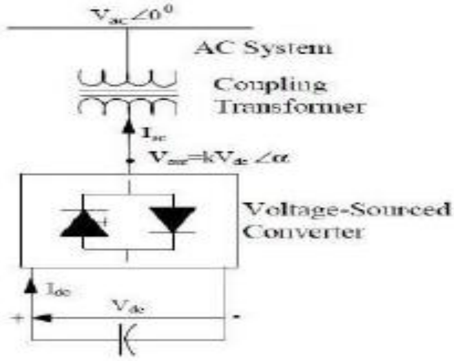


Figure 2: Functional Model of STATCOM

The relationship between fundamental component of the converter ac output voltage and Voltage across dc capacitor is given as

$$V_{out} = kV_{dc} \qquad (1)$$

where k is coefficient which depends upon on the converter configuration, number of switching pulses and the converter controls. The fundamental component of the converter output voltage, i.e., Vout can be controlled by varying the dc voltage across capacitor which can be done by changing the phase angle α of operation of the converter switches relative to the phase of the ac system bus voltage. The direction of flow of reactive power whether it is from coupling transformer to the system or from system to the coupling transformer depends upon the difference between the converter output voltage and the ac system bus voltage. The real power flowing into the converter supplies the converter losses due to switching and charges the dc capacitor to a satisfactory dc voltage level. The capacitor is charged and discharged during the course of each switching cycle but in steady state, the average capacitor voltage remains constant. If that were not the case, there would be real power flowing into or out of the converter, and the capacitor would gain or lose charge each cycle. In steady state, all of the power from the ac system is used to replenish the losses due to switching[2][12].

A. Power exchange in STATCOM -

The amount and type of power exchange between the STATCOM and the PCC (point of common coupling) can be adjusted by controlling the magnitude of STATCOM output voltage with respect to the system voltage as shown in figure 3. The STATCOM is connected at the PCC where Vo is the magnitude of STATCOM output voltage, Vpcc is the magnitude of the system voltage at PCC and Xs is the equivalent reactance between STATCOM and the system[2]. The reactive power supplied by the STATCOM is given by:

$$Q = \frac{V_0 - V_{pcc}}{X_s} V_{pcc} \qquad (2)$$

STATCOM supplies or absorbs reactive power based on the Q value either positive or negative as shown in figure 3, A STATCOM can provide full capacitive output current at any system voltage, practically down to zero[2].

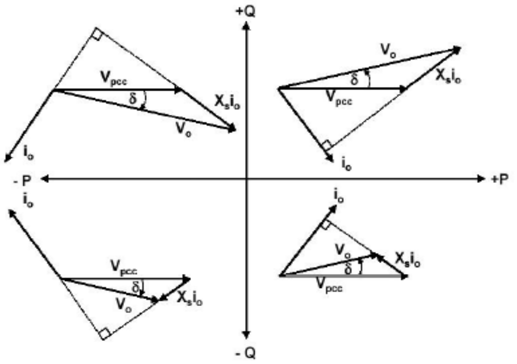
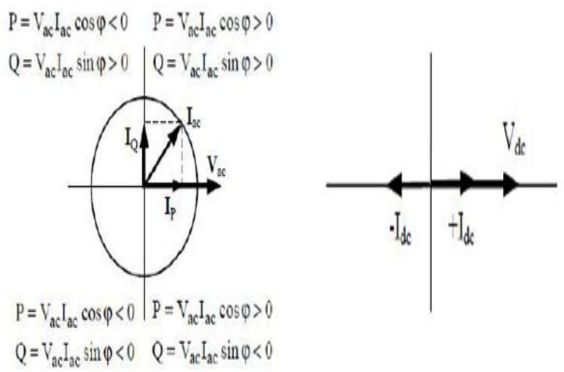


Figure 3: Operating modes of STATCOM

Figure 4(a) shows the STATCOM output current and voltage diagram where phasors IQ and IP represent the AC current Iac components that are in quadrature and in phase with the AC system voltage Vac, respectively. The DC current Idc and voltage Vdc are shown in figure 4(b). If the losses in the STATCOM circuit are neglected and it is assumed that real power exchange with the AC system is zero, then the active current component IP and DC current Idc are equal to zero and the AC current Iac is equal to the reactive component IQ[3]. Assuming that the AC current flows from the STATCOM to the AC system the AC current magnitude can be calculated as[2]:

$$I_{ac} = \frac{V_{out} - V_{ac}}{X} \qquad (3)$$

where Vout and Vac are the magnitudes of the STATCOM output voltage and AC system voltage respectively, while X represents the leakage reactance of coupling transformer.



(a) (b)

Figure 4: STATCOM phasor diagrams at (a) AC terminals (b) DC terminals

In figure 4(a), if both real and reactive power flows are positive, then the power is absorbed by the STATCOM while negative means that the power is injected by the STATCOM. The corresponding reactive power exchanged can be expressed as follows[2]:

$$Q = \frac{V_{out}^2 - V_{out} V_{ac} \cos\alpha}{X} \qquad (4)$$

where the α angle is the angle between the AC system bus voltage Vac and the STATCOM output voltage Vout. The STATCOM absorbs real power from the AC system, if the STATCOM output voltage is made to lag the AC system voltage. The amount of exchanged real power is very small in steady state; hence, the angle is also small which is approximately equal to 2°. The real power exchange between the VSC and the AC system can be calculated using[2]:

$$P = \frac{V_{ac} V_{out} \sin\alpha}{X} \qquad (5)$$

B. Modeling of STATCOM -

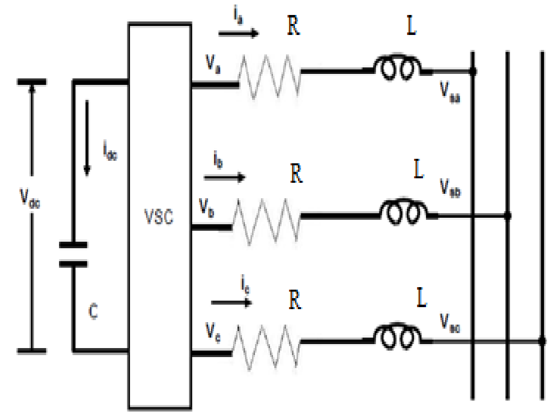


Figure 5: Equivalent circuit of STATCOM

Figure 5 shows the simplified equivalent circuit of the STATCOM. It contains a DC link capacitor, a VSC, and series inductances in the three lines connecting to the system bus. The circuit also includes resistance in series with the AC lines to represent the VSC and transformer conduction losses[3][11]. Under balanced conditions, the AC side circuit equations in figure 5 can be written in a synchronously rotating reference frame using the d-q transformation.

$$\frac{di_d}{dt} = \frac{-R}{L} i_d + \omega_s i_q + \frac{1}{L} V_d - \frac{1}{L} V_{sd} \qquad (6)$$

$$\frac{di_q}{dt} = \frac{-R}{L} i_q + \omega_s i_d + \frac{1}{L} V_q - \frac{1}{L} V_{sq} \qquad (7)$$

where R is the equivalent resistance representing the power losses, ω_s is the synchronously rotating angle speed, (id, iq), (vd, vq), and (vsd, vsq) are the dq components of (ia, ib, ic), (va, vb, vc), and (vsa, vsb, vsc), respectively. Neglecting the harmonics due to switching and the losses in the VSC and the transformer, the power balance between the AC and DC sides of the VSC is given by

$$\frac{3}{2}\left(V_{sd} i_d + V_{sq} i_{sq}\right) = V_{dc} i_{dc} \qquad (8)$$

With correct alignment of the reference frame, the Vsq term is zero, and hence, the following equation can be written to relate the DC link voltage to the d-axis current id and d axis component of the power line voltage Vsd. Assuming that the DC link voltages are balanced, their dynamics can be represented using Vdc.

$$\frac{dV_{dc}}{dt} = \frac{3V_{sd}\, i_d}{2CV_{dc}} \qquad (9)$$

where C is the total dc capacitance, Vdc is the equivalent total DC link voltage. The dynamics of the VSC can be described by a set of first order Ordinary Differential Equations (ODEs). In terms of the instantaneous variables, the reactive power balance at the PCC is given by

$$P = \frac{3}{2}\left(V_d i_d + V_q i_q\right) \qquad (10)$$

$$Q = \frac{3}{2}\left(V_q i_d + V_d i_q\right) \qquad (11)$$

Aligning the d-axis of the reference frame along the grid voltage position, Vq=0

$$P = \frac{3}{2} V_d i_d \qquad (12)$$

$$Q = \frac{3}{2} V_d i_q \qquad (13)$$

From the above equations, it can be seen that Q can be controlled through iq and P can be controlled through id [3],[11].

IV. SPACE VECTOR PULSE WIDTH MODULATION (SVPWM) CONTROL

Space vector pulse width modulation refers to a special switching sequence of power transistors of a three-phase inverter. It generates less harmonic distortion in the output voltages and or currents and to provide more efficient use of supply voltage. There are eight different combinations of switching states as follows: (000), (100), (110), (010), (011), (001), (101), and (111), which makes six active space vectors and two zero vectors that are shown in the space vector plane in figure 6. V_0, V_7 are called zero vectors and do not cause a current to flow to the load, so the line to line voltages are zero. The other six vectors, V_1 through V_6 can produce voltages to be applied to the load terminals. The magnitudes of all six active vectors are equal and there is a 60° phase displacement between each two adjacent vectors[7][10].

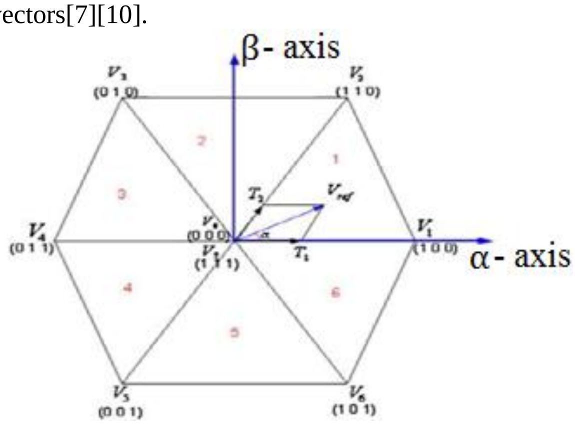


Figure 6: Space Vector Diagram with Sectors

The objective of space vector PWM technique is to approximate the reference voltage vector V_{ref} using the eight switching patterns. In the each sector V_{ref} is obtainable by switching on, for a proper time, two adjacent vectors[7][10]. Presented in figure 6, the reference vector V_{ref} can be implemented by the switching vectors of V_1, V_2 and zero vectors V_0, V_7.

A. Calculation of time period for sector I -

To implement the space vector PWM, the voltage equations in the ABC reference frame can be transformed into the stationary αβ reference frame by using Clarke transformation. From figure 7, we can write

$$\left|\vec{V}_{ref}\right| = \sqrt{V_\alpha^2 + V_\beta^2}$$

$$\alpha = \tan^{-1}\left(\frac{V_\beta}{V_\alpha}\right) = \omega t = 2\pi f t,$$

where f= fundamental frequency and α is angle between V_{ref} and V_α.

At sector 1, V_1 and V_2 are voltage vectors. T_s is switching time interval at which output voltage of inverter is constant. T_1 and T_2 are switching time duration of voltage space vectors V_1 and V_2[7]. The times T_1 and T_2 are obtained from simple trigonometric relationships as described in figure 7.

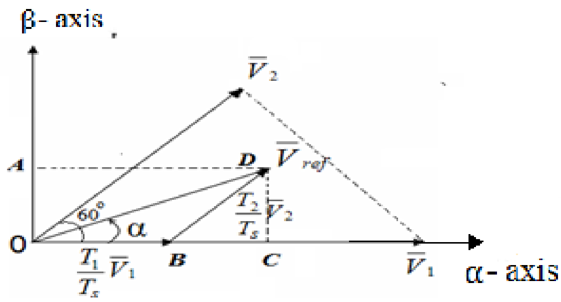


Figure 7: Reference vector with respect to Sector I

$$V_{ref} = \left(\frac{T_1}{T_s}\right) V_1 + \left(\frac{T_2}{T_s}\right) V_2$$

$$\left(\frac{T_1}{T_s}\right) V_1 = V_{ref}\cos\alpha - BC = V_{ref}\cos\alpha - DC\tan 30°$$

$$= \frac{2}{\sqrt{3}} V_{ref} \sin(60° - \alpha) \qquad (14)$$

$$\left(\frac{T_2}{T_s}\right) V_2 = \frac{AO}{\cos 30°} = \frac{V_{ref}\sin\alpha}{\frac{\sqrt{3}}{2}}$$

$$= \frac{2}{\sqrt{3}} V_{ref} \sin\alpha \qquad (15)$$

where, $0 \le \alpha \le 60°$.

As the amplitude of V_1 and V_2 are equal to $2V_{dc}/3$ [7], hence from equations (14) and (15), following equations are obtained.

$$T_1 = T_s . A . \frac{\sin\left(\frac{\pi}{3} - \alpha\right)}{\sin\frac{\pi}{3}} \qquad (16)$$

$$T_2 = T_s . A . \frac{\sin(\alpha)}{\sin\frac{\pi}{3}} \qquad (17)$$

$$T_0 = T_s - (T_1 + T_2)\,, \qquad (18)$$

where, $T_s = \frac{1}{f_s}$ and $A = \frac{|V_{ref}|}{\frac{2}{3}V_{dc}}$

B. Switching time duration at any sector (T_1, T_2, T_0) -

Switching time at any sector can be illustrated in equation (19) to (21). For 'n' number of samples T_1, T_2 and T_0 are [7][10],

$$T_1 = \frac{\sqrt{3}\,T_s\,|V_{ref}|}{V_{dc}}\left(\sin\left(\frac{\pi}{3} - \alpha + \frac{n-1}{3}\pi\right)\right)$$

$$= \frac{\sqrt{3}\,T_s\,|V_{ref}|}{V_{dc}}\left(\sin\left(\frac{n\pi}{3} - \alpha\right)\right) \qquad (19)$$

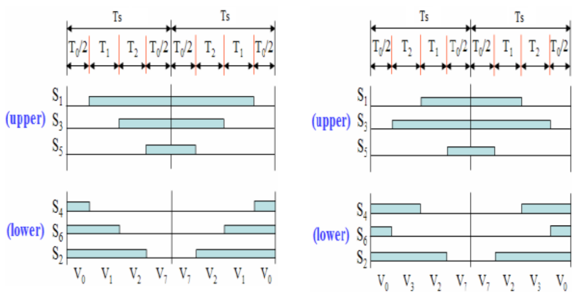
$$T_2 = \frac{\sqrt{3}\,T_s\,|V_{ref}|}{V_{dc}}\left(\sin\left(\alpha - \frac{n-1}{3}\pi\right)\right) \qquad (20)$$

$$T_{0} = T_s - (T_1 + T_2) \qquad (21)$$

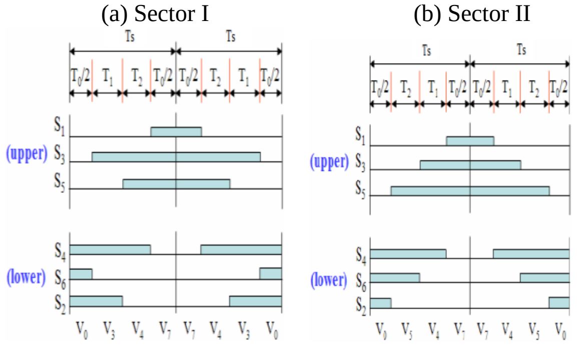
where, n=1 through 6 (that is sector 1 to 6), $0 \leq \alpha \leq 60°$.

C. Determination of switching time -

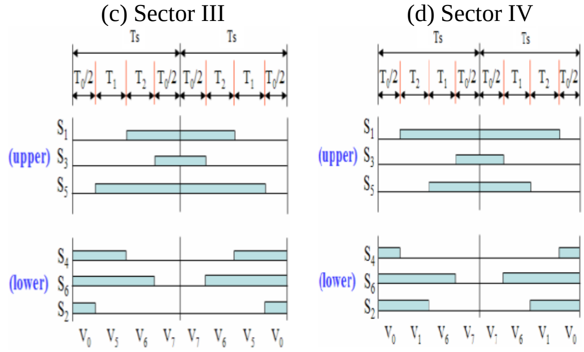
After computing the active and zero state times for a particular modulation cycle, it is possible to produce the switching signals to be applied to the inverter. Inverter switching signals for SVPWM in sector 1 to 6 are shown in figure 8 and summarized in table 1 for all vectors[7][10].



(a) Sector I (b) Sector II



(c) Sector III (d) Sector IV



(e) Sector V (f) Sector VI

Figure 8: Space Vector PWM switching patterns at each sector

Table 1 shows the 6 sectors and the time calculation of each switch. This can be easily calculated using above switching states.

Table 1: Switching ON time at each sector

Sector	Upper switch	Lower switch
1	$S_1 = T_1 + T_2 + T_0/2$ $S_3 = T_2 + T_0/2$ $S_5 = T_0/2$	$S_4 = T_0/2$ $S_6 = T_1 + T_0/2$ $S_2 = T_1 + T_2 + T_0/2$
2	$S_1 = T_1 + T_0/2$ $S_3 = T_1 + T_2 + T_0/2$ $S_5 = T_0/2$	$S_4 = T_2 + T_0/2$ $S_6 = T_0/2$ $S_2 = T_1 + T_2 + T_0/2$
3	$S_1 = T_0/2$ $S_3 = T_1 + T_2 + T_0/2$ $S_5 = T_2 + T_0/2$	$S_4 = T_1 + T_2 + T_0/2$ $S_6 = T_0/2$ $S_2 = T_1 + T_0/2$
4	$S_1 = T_0/2$ $S_3 = T_1 + T_0/2$ $S_5 = T_1 + T_2 + T_0/2$	$S_4 = T_1 + T_2 + T_0/2$ $S_6 = T_2 + T_0/2$ $S_2 = T_0/2$
5	$S_1 = T_2 + T_0/2$ $S_3 = T_0/2$ $S_5 = T_1 + T_2 + T_0/2$	$S_4 = T_1 + T_0/2$ $S_6 = T_1 + T_2 + T_0/2$ $S_2 = T_0/2$
6	$S_1 = T_1 + T_2 + T_0/2$ $S_3 = T_0/2$ $S_5 = T_1 + T_0/2$	$S_4 = T_0/2$ $S_6 = T_1 + T_2 + T_0/2$ $S_2 = T_2 + T_0/2$

V. PROPORTIONAL-INTEGRAL CONTROLLER

SVPWM gets input from the proportional-integral controller. A proportional-Integral (PI) controller is a control loop feedback mechanism (controller) widely used in industrial control systems . A PI is the most commonly used controller and it calculates an "error" value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process control inputs. The proportional and integral values are denoted as P and I [9]. Block diagram of system with PI controller is shown in figure 9. The transfer function of the PI controller is defined as follows.

$$G_c(s) = K_P + \frac{K_i}{s} \qquad (22)$$

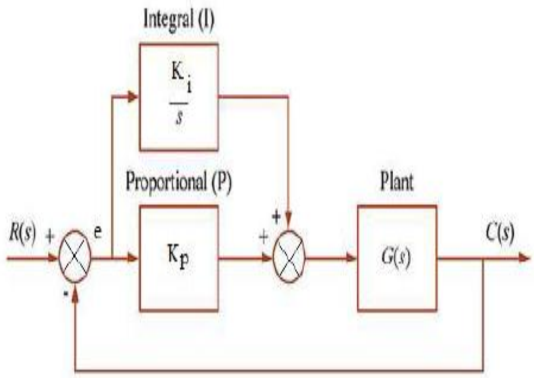


Figure 9: Block diagram of system with PI Controller

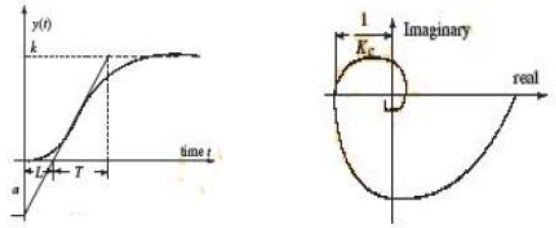
A. Ziegler–Nichols tuning method of PI controller -

For designing the PI controller, the values of controller parameters K_p and K_i are obtained through a very useful empirical formula proposed by Ziegler and Nichols in early 1942. The tuning formula is obtained when the plant model is given by a first order plus dead time (FOPDT) which can be expressed by

$$G(s) = \frac{k}{1+sT} e^{-sL} \qquad (23)$$

where, L is dead time, T is process time constant, k is process gain. In real time process control systems, a large variety of plants can be approximately modeled according to equation (23)[9]. If the system model cannot be physically derived, experiments can be performed to extract the parameters for the approximate model given by equation (23). For instance, if the step response of the plant model can be measured through an experiment, the output signal can be recorded as sketched in figure 10(a), from which the parameters of k, L, and T (or a, where a = kL/T) can be extracted by the simple approach shown[9]. This is open loop tuning method. With L and a, the Ziegler–Nichols formula in table 2 can be used to get the controller parameters.

If a frequency response experiment can be performed, the crossover frequency ω_c and the ultimate gain K_c can be obtained from the Nyquist plot as shown in figure 10(b). Let ultimate period $T_C = 2\pi/\omega_c$. The controller parameters can also be retrieved from table 2. This is closed loop tuning method. Since only the 180° point on the Nyquist locus is used in this approach, Ziegler and Nichols suggested it can be found by putting the controller in the proportional mode and increasing the gain until an oscillation takes place. The point is then obtained from measurement of the gain and the oscillation frequency[9].



(a) Time response (b) Frequency response

Figure 10: Sketches of the response of an FOPDT model

Table 2: The Ziegler-Nichols tuning formulae

Controller type	From time response			From frequency response		
	K_p	K_i	K_d	K_p	K_i	K_d
P	1/a	-	-	$0.5K_c$	-	-
PI	0.9/a	3L	-	$0.4K_c$	$0.8T_c$	-
PID	1.2/a	2L	L/2	$0.6K_c$	$0.5T_c$	$0.12T_c$

By using Ziegler-Nichols time response tuning method, value of L is 1.66×10^{-3}, T is 9.222×10^{-7} and a is 1800. Therefore, proportional gain of PI controller is found to be 0.0005 and integral gain is found to be 0.005 using formulae given in table 2. The advantages of the Ziegler-Nichols method is that the tuning rules are very simple to use and it includes dynamics of whole process, which gives a more accurate picture of how the system is behaving[9].

VI. MATLAB SIMULINK MODEL

The complete MATLAB simulink model designed for damping oscillations using STATCOM is shown in figure 11 and the corresponding various system parameters are tabulated in table 3.

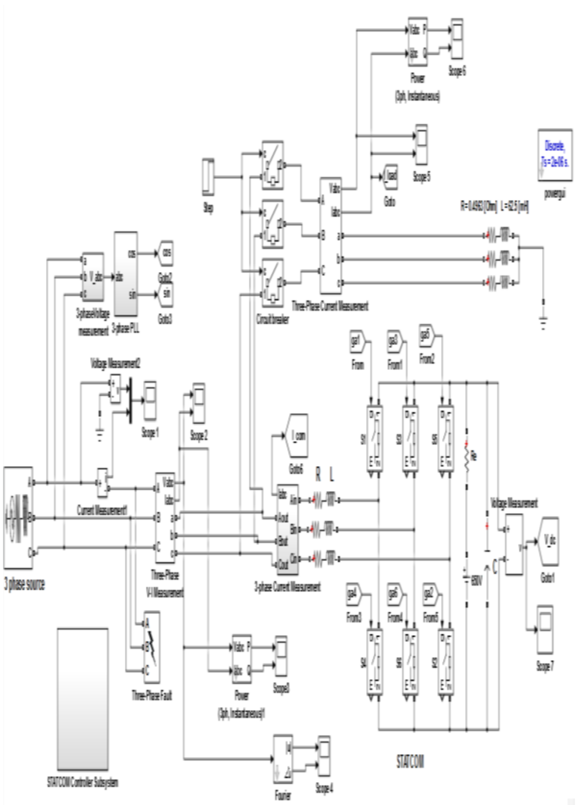


Figure 11: Complete MATLAB simulink model of proposed system with STATCOM

Table 3: Various parameters of MATLAB simulink model

Sr. No.	MATLAB Simulink block	Parameter specifications
1	Three phase source (200KVA)	Phase to phase rms voltage = $240\sqrt{3}$ V; Frequency = 50Hz; Internal winding connection = Star connected with ground; Three phase short circuit level at base voltage (KVA) = 200 KVA; Base voltage = $240\sqrt{3}$ V; X/R Ratio = 7.

2	Three phase fault	Fault type = Line to ground fault ; Fault resistance = 0.001 Ohm; Transition time: Fault start time 0.4 sec and fault end time 0.6 sec; Snubber resistance = 1 MOhm.
3	Breaker (1 phase)	Breaker resistance = 0.01 Ohm; Initial state of breaker = Open; Closing time = 0.2 sec; Snubber resistance = 1 MOhm.
4	Series RL Load	Resistance = 0.4963 Ω, L= 62.5 mH.
5	Ideal switch	Internal resistance = 0.001 Ohm; Initial state of switch = Open; Snubber resistance = $1*10^5$ Ohm.
6	STATCOM	200 kVAr
7	Choke	300 μH
8	DC link capacitor	2619 μF, 650 V

A. STATCOM controller subsystem -

Subsystem of controller for controlling the pulses given to the STATCOM is shown in figure 12.

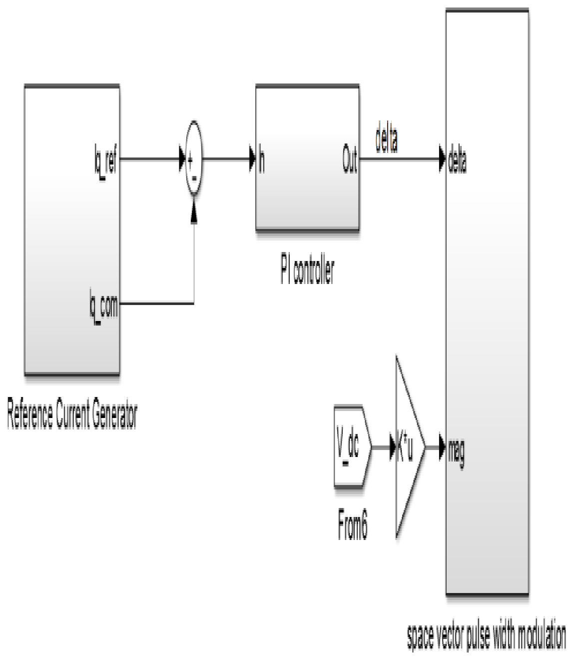


Figure 12: STATCOM controller subsystem

B. Reference current generator -

Reference current generator consists of subsystem of abc to dq transformation of load current and compensator current. Quadrature axis components of currents are taken for reference whose difference is given as input to the PI controller.

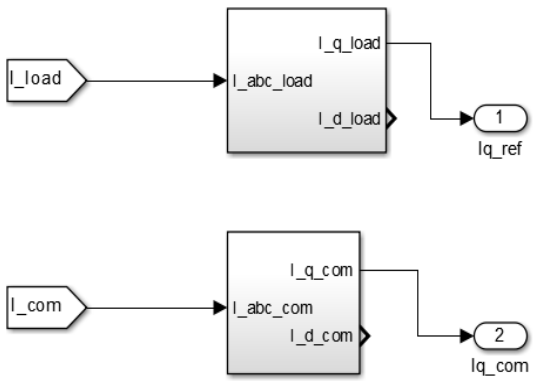


Figure 13: Reference current generator

C. PI controller subsystem -

PI controller block is shown in figure 14 and corresponding parameter specifications are tabulated in table 4. Input to this controller is difference of quadrature components of load current and compensator current. PI controller will manipulate this error and give output of an angle delta to SVPWM for generating pulses for STATCOM.

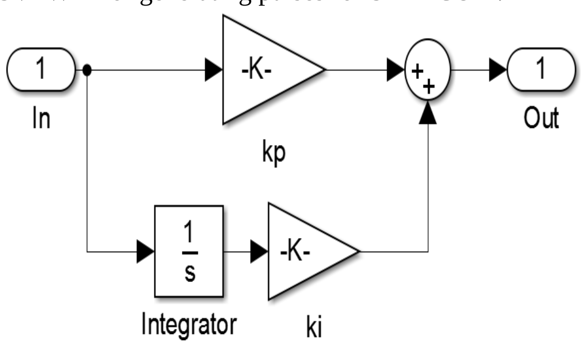


Figure 14: MATLAB subsystem of PI Controller for controlling switching pulses

Table 4: Parameter specifications of PI controller subsystem

Sr. No.	MATLAB Simulink block	Parameter specification
1	PI Controller	Proportional gain Kp= 0.0005; Integral gain Ki = 0.005.

D. Space vector pulse width modulation subsystem -

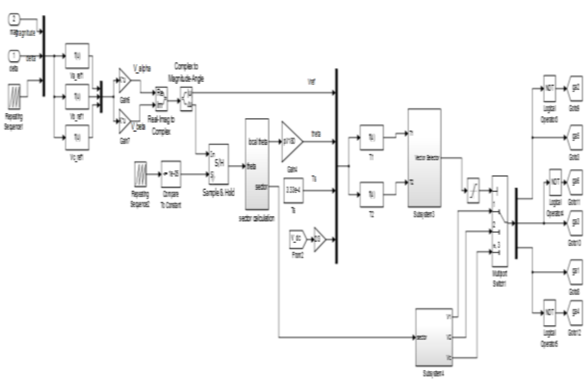


Figure 15: Space vector PWM subsystem for generation of gate pulses

Output of PI controller is given to the space vector pulse width modulation subsystem which generates gate pulses for the STATCOM. Figure 15 represents the space vector PWM subsystem. SVPWM generates gates pulses to be given to the STATCOM.

VII. MATLAB SIMULATION RESULTS

The simulation results of MATLAB simulink model of proposed system for normal and fault condition are given here. Load is connected at 0.2 seconds.

A. Simulation results during normal condition -

Figure 16 shows three phase voltage and current of generator during normal condition. It represents the voltage and current during normal condition to be supplied to the load.

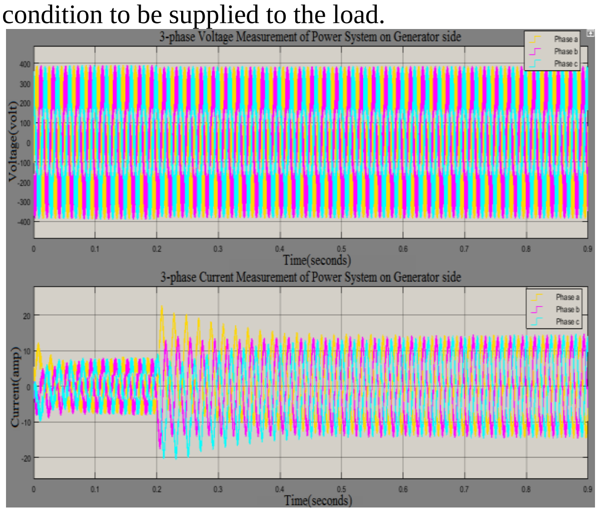


Figure 16: Three phase VI measurement of generator during normal condition

Figure 17 represents the waveforms for active and reactive power supplied by generator during normal condition when load is connected at 0.2 seconds.

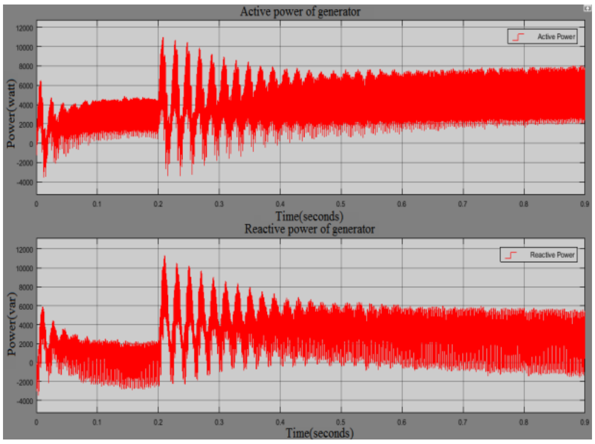


Figure 17: Active and reactive power of generator during normal condition

Figure 18 shows voltage and current of inductive load which is connected at 0.2 seconds in the power system during normal condition.

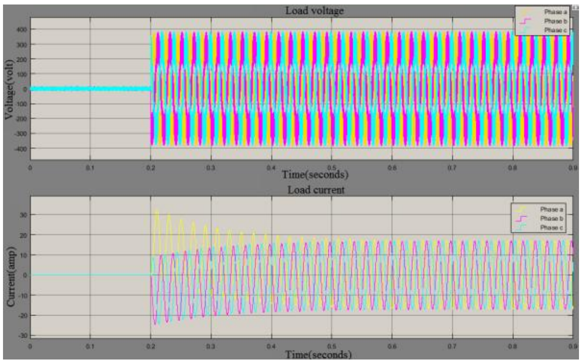


Figure 18: Load voltage and current during normal condition

Waveforms for active and reactive power of load connected at 0.2 seconds under normal condition are as shown in figure 19.

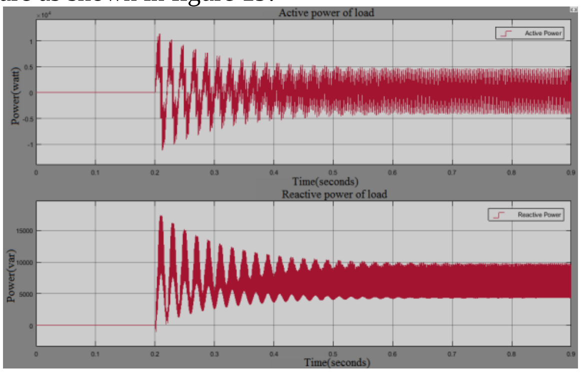


Figure 19: Active and reactive power of load during normal condition

B. Simulation results during fault condition -

A line to ground (LG) fault is introduced in phase 'a' of the power system at 0.4 seconds and cleared at 0.6 seconds. Figure 20 shows three phase voltage and current measurement of generator during fault condition.

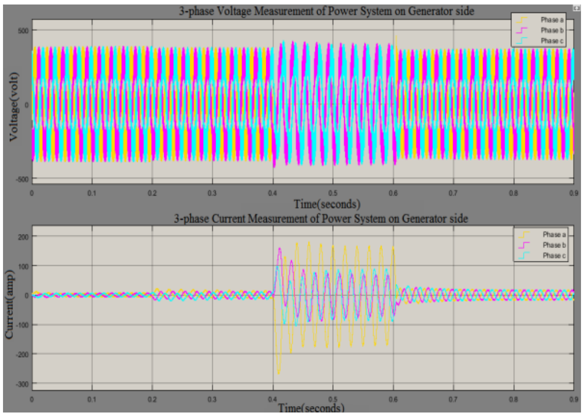


Figure 20: Three phase VI measurement of generator during fault condition

It is clear from figure 20 that before the occurrence of fault i.e. before 0.4 seconds, values of voltage and current are varying smoothly within a certain limit but when fault occurs at 0.4 seconds, there is sudden rise in current and voltage of phase drops to zero. This sudden rise in current serves an oscillatory behaviour during 0.4 to 0.6 seconds. Due to this, currents in other two phases are also disturbed during 0.4 to 0.6 seconds. This huge amount of current if given directly to load will damage the load.

Figure 21 shows the waveforms for active power and reactive power of generator during fault condition. Oscillations in power due to fault can be seen between 0.4 to 0.6 seconds. These oscillations can cause load to damage if proper action is not taken.

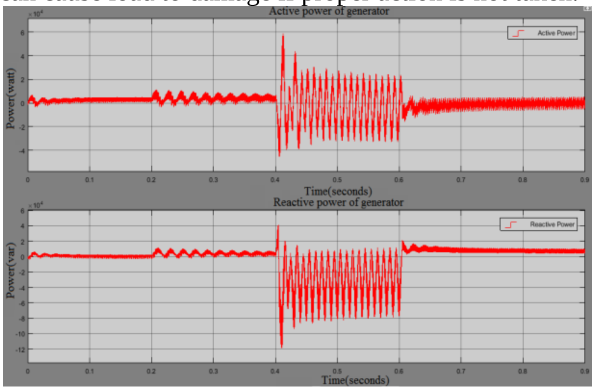


Figure 21: Active and reactive power of generator during fault condition

Figure 22 shows the voltage and current of inductive load during fault condition. The increased value of current which was present on generator side got damped with the help of STATCOM which can be clearly seen from figure 22.

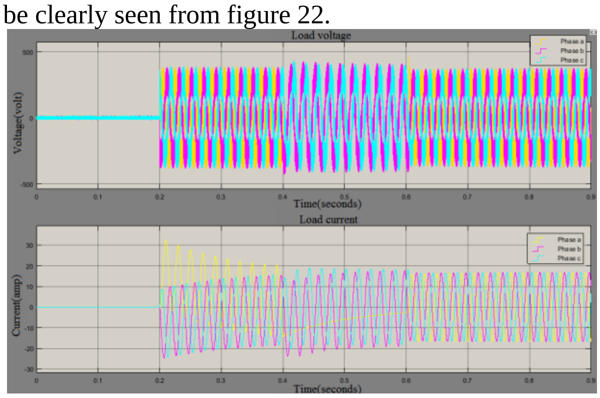


Figure 22: Load voltage and current during fault condition

Figure 23 shows the active power and reactive power of load during fault condition. Oscillations in power which were present during 0.4 to 0.6 seconds are now damped as shown in figure 23 with the help of STATCOM.

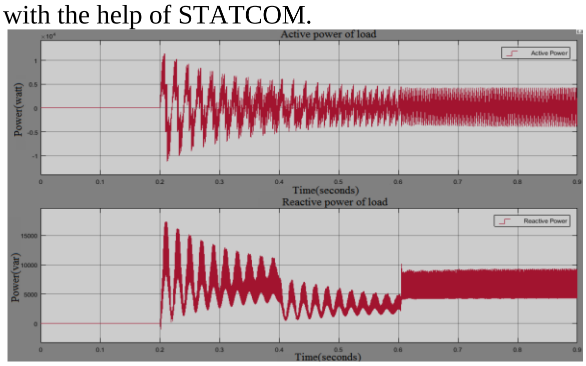


Figure 23: Active and reactive power of load during fault condition

Thus, by observing various waveforms shown above for normal and fault condition, it is clear that with the help of STATCOM, oscillations in power system can be damped out and load can be protected.

VIII. CONCLUSION AND FUTURE SCOPE

It has demonstrated how important it is for any electrical system to have a well designed FACTS device to protect the system. If fault occurs in the system, it results in large oscillations in the current and hence power to be supplied to the load without any controller. It can be observed with STATCOM, these oscillations were damped out. If the STATCOM is not available, it will lead to instability, may also cause the power system to damage if proper action is not taken. Thus, STATCOM helps in maintaining stability of the system. In future, STATCOM can be developed using multi-pulse voltage source converters which minimizes the injection of harmonic voltages. The STATCOM controller can be further implemented using fuzzy-PI control or artificial neural networks.

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